Laboratory Gases

CEU 261

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This chapter describes the design criteria and central piping distribution methods for various laboratory-grade specialty gas systems, including pure compressed air. For the purposes of this chapter, a compressed gas is any gas at a pressure higher than atmospheric pressure. Also included in the discussion are various specialty compressed air and gas systems typically used for organic and inorganic chemistry, physics, and biological laboratories and those used for research, development, and commercial purposes. The gases and their delivery systems used in these types of facilities are characterized by low delivery pressures, low and intermittent volumes, and high-purity requirements. This chapter concentrates on cylinder and dewar supplies and the local generation of such gases.

For a discussion of all phases of standard compressed air, compressor types, compressor accessories, fundamentals, and definitions not discussed here, refer to Chapter 9 of this volume. For a discussion of medical air for healthcare facilities, refer to Chapter 2.

CODES AND STANDARDS

The building codes and standards impacting the design and installation of the various specialty gas systems have been put in place to protect the safety and health of operating personnel and building occupants. The building codes also have requirements concerning fire and the structural consequences of accidents. However, no mandated code requirements have been written concerning the sizing or purity of any of the specialty gases. These requirements are usually specific to the type of facility and end use.

Minimum purity requirements, called commodity standards, are listed in Compressed Gas Association (CGA) standards for the various gases. Often, the actual on-site purity requirement is higher than that listed in the standard and is determined by the proposed use of the gas and the requirements of the user. CGA also publishes material, pressure, and dimensional standards for pipe connections and terminations.

The National Fire Protection Association (NFPA) publishes codes for the storage of flammable gases both inside and outside a building. NFPA 55: *Compressed Gases and Cryogenic Fluids Code* covers bulk oxygen at consumer sites and the storage of hydrogen. NFPA 99: *Health Care Facilities Code* provides requirements for the storage of flammable and nonflammable gases in cylinders. This standard does not actually apply to laboratories outside of healthcare facilities, but it often is used for guidance in determining the amount and location of these cylinders. The final decision to adhere to provisions of this standard depends on the client, the requirements of the client's insurance carrier, and the authority having jurisdiction (AHJ).

The U.S. Environmental Protection Agency (EPA) provides health hazard classifications, fire hazard classifications, and sudden release of pressure hazard classifications. All of these ratings and the associated precautions are available on material safety data sheets (MSDS). For instance, gases that fall under the "Reactive Hazard" classification must be kept separate from each other, typically using walls, nonpermanent solid separators available from the gas supplier, or gas cabinets. The EPA also publishes threshold limit values for the degree of concentration of any particular gas in ambient air for breathing purposes.

PURIFIED AIR FUNDAMENTALS

Because purified air is a specialty gas, it is important for the engineer to analyze standard laboratory (free) air to determine if the end use requires further air purification and how to select equipment to accomplish this.

Free air is a mixture of many elements and compounds. (The composition of dry air is listed in Table 9-1.) Pure air is odorless, tasteless, and free of chemicals unless some foreign matter is suspended in the mixture in error.

The air pressure exerted at the Earth's surface is due to the weight of the column of air above that point and is measured barometrically at a standard pressure of 14.7 pounds per square inch gauge (psig) (101.4 kPa). Because free air is less dense at higher elevations, a correction factor must be used for standard air to determine the equivalent volume at the higher elevation. (Elevation correction factors are given in Table 9-2.) By multiplying the volume of air at sea level by the correction factor, the actual quantity of air at a higher elevation can be found.

Temperature is also a consideration. Because an equal volume of any gas at a lower temperature will exert a higher pressure at a higher temperature, a correction factor must be used to determine the equivalent volume of air at different temperatures. (Temperature correction factors are given in Table 9-3.) By multiplying the volume of air at the lower temperature by the correction factor, the actual quantity of free air at the higher temperature can be found.

Impurities and Contamination

Knowledge of the various pollutants in the air is necessary when determining the equipment required to effectively reduce or remove them, and the air must be tested to achieve this knowledge. When selecting appropriate and specific air purification components, remember that no single piece of equipment or device can accomplish the job of removing all contaminants.

The required level of protection from the various contaminants depends on the purpose for which the air will be used. As well as identifying and quantifying the pollutants, the performance criteria for each individual system also must be determined prior to selecting any equipment.

The four general classes of contaminants are liquids (oil and water), vapor (oil, water, and hydrocarbons), gases, and particulates.

Liquids

Water enters a system with the intake air, passes through the compressor as a vapor, and condenses afterward into liquid droplets. When water settles on or within pipes, corrosion begins, ultimately ruining equipment and causing product rejection and contamination. Water also allows microorganisms to grow.

Most liquid oil contamination originates at the intake location or in an oil-lubricated compressor. As the droplets are swept through the system at velocities approaching 4,000 feet per minute (fpm) (1,200 m/min), they gradually erode obstructions in their path by repeated collisions. At high temperatures, oils break down to form acids. In the presence of particulates, oil forms sludge. Oil also can act like water droplets and cause erosion.

Liquid chemicals react with water and also corrode surfaces. There is no safe level of liquids in the airstream. They should be removed as completely as practical.

Vapor

Water vapor is the most common contaminant to enter the system. Oil, water, and chemical vapors enter the system in the same manner as liquids and contribute to the corrosion of surfaces in contact with the air. Oil vapor reacts with oxygen to form varnish buildup on surfaces. Various chemicals also cause corrosion and are often toxic.

The level of acceptable water vapor varies with end-use requirements. A dewpoint of -30°F (-34°C) is required to minimize corrosion in pipelines. For critical applications, a dewpoint of -100°F (-73°C) may be required. Oil vapor remaining in the air should be reduced to as close to zero as practical. Chemical concentrations should be reduced to zero where practical.

Gas

Gases in any quantity that are potentially harmful to the system or process requirements should be reduced to zero or to a point that will cause no harm depending on practical considerations. Condensable hydrocarbons should be removed as completely as practical. Gases such as carbon dioxide, sulfur dioxide, and nitrogen compounds react with heat and water to form acids.

Particulates

Particulates enter the system from the air intake, originate in the compressor due to mechanical action, or are released from some air-drying systems. These particles erode piping and valves and can contaminate products. However, the most harmful effect is that they clog the orifices or passages of, for example, tools at end-use points. These particulates include metal fines, carbon and Teflon particles, pollen, dust, rust, and scale.

Particulate contamination must be reduced to a level low enough to minimize end-use clogging, product rejection, or process contamination. These values must be established by the engineer and client and will vary widely. The general size of particles in a typical system is between 10 and 0.01 micrometer (μm) in diameter.

Water Vapor in Compressed Air

Water vapor is present in all free air and is the most common contaminant. In many cases, it will be necessary to remove any water vapor above that required for air normally used for general laboratory purposes.

Saturated Air and Dry Air

Saturated air contains the maximum amount of water vapor possible based on its temperature and pressure. Dry air contains no water vapor. To determine the moisture content of saturated air (100 percent relative humidity) based on its temperature, refer to Figure 12-1.

Relative Humidity

Relative humidity is the amount of water vapor present in air expressed as a percent of the total amount capable of being present when the air is saturated. Relative humidity depends on pressure and temperature and is not the preferred method to refer to water vapor in air.

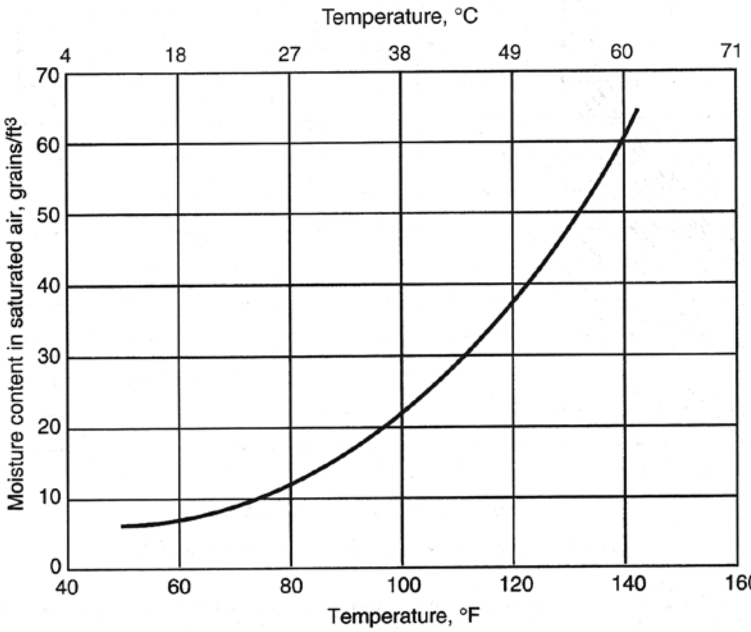

Figure 12-1 Moisture Content of Saturated Air

Dewpoint

The dewpoint is the temperature at which water in the air starts to condense on a surface. It is the preferred method used to express the dryness of compressed air since it does not depend on temperature. As the dewpoint decreases, the air gets dryer. Since the dewpoint of air varies with air pressure, it is referred to as the pressure dewpoint.

To find the dewpoint of air at various pressures and temperatures, refer to the dewpoint conversion chart in Chapter 9 (Figure 9-2).

SPECIALTY LABORATORY GASES

Specialty laboratory gases are prepared to perform specific tasks. Examples include the following:

- Span and calibration gases to calibrate gas chromatographs
- Carrier gases to exclude impurities and sweep a sample through a column
- Process gases to promote specific reactions
- Gases for analysis functions

Specialty compressed gases are classified into the following general categories:

- Oxidizers are nonflammable but support combustion. No oil or grease is permitted to be used with any device associated with the use of this type of gas, and combustibles shall not be stored near these gases. Oxygen is an example.
- Inert gases, such as helium, do not react with other materials. If released into a confined space, they will reduce the oxygen level to a point that asphyxiation could occur. Rooms where these gases are stored should be provided with oxygen monitors and should be well ventilated.
- Flammable gases are those that, when combined with air or oxidizers, will form a mixture that will burn or possibly explode if ignited. Flammable mixtures have range of concentration below which they are too lean to be ignited and above which they are too rich to burn. The most often-used figure is the low-explosive level (LEL), which is the minimum percent by volume that will form flammable mixture at normal temperatures and pressures. The high level for alarms generally one-half of the LEL, with warnings issued at one-tenth of the LEL. The area where flammable gases are stored must be well ventilated, contain approved electrical devices suitable for explosive atmospheres, and restrict ignition sources. The flammability limits of common gases are given in Table 12-1.
- Corrosive gases will attack the surface of certain substances and also damage human tissue upon contact.
- Toxic and poisonous gases will harm human tissue by contact or ingestion. Protective clothing and equipment must be used.
- Pyrophoric gases will spontaneously ignite upon contact with air under normal conditions.
- Cryogenic gases are stored as extremely cold liquids under moderate pressure and are vaporized when used. If the liquid is spilled on bare skin, the skin will burn, and splashing into the eyes will cause blindness.

Table 12-1 Flammability Limits and Specific Gravities of Common Gases

Gas	Specific Gravity	Flammability in Air, %	
		Low	High
Acetylene	0.906	25	100
Air	1.00		
Ammonia	0.560	15	28
Argon	1.38		
Arsine	2.69	5.1	78
Butane	0.600	1.8	8.4
Carbon dioxide	1.52		
Carbon monoxide	0.967	12.5	74
Chlorine	2.49		
Cyclopropane	0.720	2.4	10.4
Ethane	1.05	3.0	12.4
Ethylene	0.570	2.7	36
Ethyl chloride	2.22	3.8	15.4
Fluorine	1.31		
Helium	0.138		
Hydrogen	0.069	4.0	75
Hydrogen sulfide	1.18	4.0	44
Isobutane	2.01	1.8	9.6
Isopentane	2.48		
Krypton	2.89		
Methan	0.415	5.0	15
Methyl chloride	1.74	10.7	17.4
Natural gas	0.600		
Neon	0.674		
Nitrogen	0.966		
Nitrous oxide	1.53		
Oxygen	1.10		
Phosgene	1.39		
Propane	1.580	2.1	9.5
Silane	1.11	1.5	98
Sulphur dioxide	2.26		
Xenon	4.53		

Grades of Specialty Laboratory Gases

Many grades of pure and mixed gases are available. Due to the lack of an industry-recognized standard grade designation for purity, each supplier has its own individual designations. It is possible for the same gas used for different purposes or provided by a different supplier to have different designations for the same purity. The instrument manufacturer and the end user must be consulted to learn the maximum acceptable levels for the various impurities based on the type of instrument used and the analytical work to be performed. The supplier then must be informed of these requirements to determine what grade of gas to supply to meet the levels of the various impurities.

The following list, although not complete, covers some manufacturers' designations for different grades of gases:

- Research grade
- Carrier grade
- Zero gas
- Ultra zero
- Ultra-high purity plus
- Ultra-high purity
- Purified
- USP (United States Pharmacopeia)

Specific instruments have additional grades, such as the Hall grade of gas.

STORAGE AND GENERATION OF GASES

Cylinder Storage

It is convenient and inexpensive to store compressed gases in cylinders (see Figure 12-2). Cylinders are available in various pressure ratings, with the nomenclature differing among the manufacturers. High-pressure cylinders store gas at pressures ranging up to 6,000 psig (41,368.5

kPa), with the most common pressures between 2,000 and 2,500 psig (13,789.5 and 17,236.9 kPa). Low-pressure cylinders or dewars store gases at pressures up to 480 psig (3,309.5 kPa).

When more than one cylinder is used to supply a system, the multiple arrangement is referred to as a bank of cylinders. Cylinder banks generally are classified as primary, secondary, and reserve based on end-use requirements. They are connected by a header and controlled by a manifold assembly. The arrangement of the cylinders is determined by the space available for the installation and the relative ease desired to change the cylinders. They can be placed in a single row, double row, or staggered. Any additional space between banks of cylinders required for specialized devices such as manifold controls, purging devices, filters, and purifiers should be added to the cylinder bank dimensions.

Cylinders do not have a standard capacity from one supplier to another. If the actual capacity of a cylinder must be determined, it can be found using Equation 2-1 in this volume.

Cylinders are available in four general categories. The first is the plain carbon steel tank. The second is called the ultra-clean tank, which is made of a slightly different alloy steel and has been completely cleaned, prepared, and dried to reduce contaminants in the cylinder. The third classification is aluminum tanks, in which the tank interior has been specially prepared and the walls treated to maintain stability and reduce particulates. Aluminum is used for cleanliness and for gases that will react with steel. In many cases, the exterior also is treated to be easily cleaned, such as required for clean room installations. The fourth type of cylinder is made of stainless steel, which is often used for ultra-pure gases.

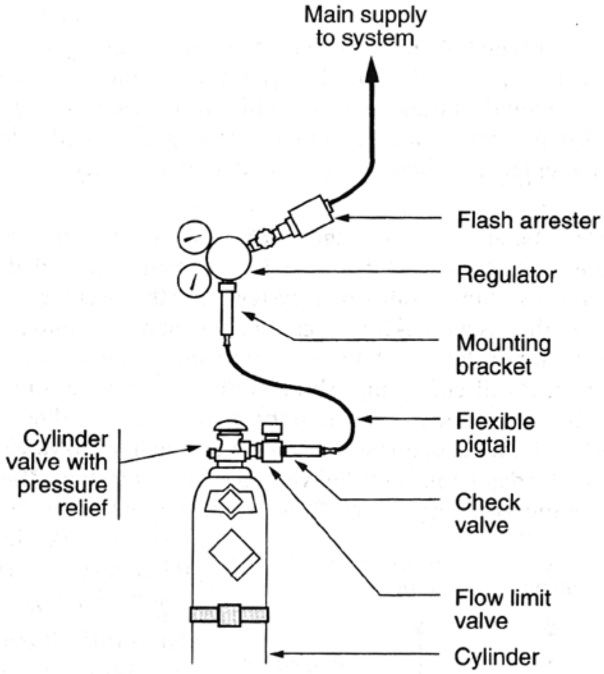

Figure 12-2 Cylinder Components

Following are the general recommendations for the installation and storage of cylinders:

- The room or area in which the cylinders are placed shall have adequate ventilation, not contain combustible materials, and be separated from sources of ignition.
- Consideration should be given for the storage of additional full and empty cylinders in the same room for convenience.
- Sufficient room should be allowed for the easy changing of cylinders. They are brought in on a hand truck or cart, and room, usually 3 feet (0.91 m), should be allowed for their maneuvering.
- Gas cylinders in active use shall be secured against falling by means of floor stands, wall brackets, or bench brackets. Straps are used to attach the cylinders to the bracket. Also available are floor racks and stands that can be provided for the installation and support of cylinders that cannot be located near walls.
- Empty cylinders also shall be secured against falling.

Dewars

When a large amount of gas storage is desired, dewars typically are used. Dewars should be placed at least 3 inches (1.5 cm) apart for easy changing.

Gas Cabinet

When toxic or reactive gases are used, the cylinders should be placed in a vented gas cabinet. The basic purpose of the cabinet is to isolate the cylinders and to contain gases in the event of a leak. Escaped gases shall be directed away from the immediate vicinity of the cylinder and cylinder storage area to a point outside the building where they can be diluted with the outside air.

The typical cabinet construction is 11-gauge painted steel or thicker to provide a one-half hour fire rating. The cabinet can contain panel-mounted manifolds, purging equipment, and other devices to allow some degree of control of operating parameters. They also can be provided with vertical and horizontal adjustable cylinder brackets. The following options also are available on the cylinder cabinet:

- Automatic shutoff of gas in the event of a catastrophic failure (flow limit)
- Purging of gas lines after cylinder changes
- Mechanical cabinet exhaust (typically 13 air changes per minute with the access window open)
- A sprinkler head for flammable gases, typically rated at 135°F (57.2°C) with a minimum water pressure of 25 psig (172.4 kPa)
- For toxic and reactive gases, a small access window could be provided to operate the valves without opening the main door and compromising the exhaust system. A fixed access window is acceptable for inert gases.

Specialty Gas Generators

In some cases, it is more desirable for a small facility to generate its own high-purity specialty gases rather than having them supplied in cylinders. A limited number of gases is available for which the anticipated volume allows this choice in laboratory or research facilities. Among them are nitrogen, hydrogen, helium, and compressed air. The generating units have their own filters and purifiers that can create gases of ultra-high purity. In particular, the use of these units for the generation of hydrogen eliminates flammable cylinders in the laboratory or separate storage areas and keeps the actual amount of gas stored below that needed for explosion to take place. These units may need to be supplied with utilities such as electrical power, compressed air, or deionized water.

DISTRIBUTION SYSTEM COMPONENTS

The components that distribute high-purity gas are different than those that distribute standard laboratory gases. Following is a discussion of only those accessories and considerations that are necessary to accomplish higher purity.

Manifolds

A manifold is an assembly used to connect multiple cylinders. This assembly also could contain regulators, shutoff valves, gauges, etc. A header with individual shutoff valves and connecting pigtails is used to physically connect several cylinders to the manifold. Manifolds can be constructed of high-purity and other special materials compatible with any specific gas being used. The most often-used materials for the header, manifold, interconnecting piping, and fittings are brass and stainless steel, with stainless steel flexible connections used to connect the cylinders to the header.

When use is intermittent and demand is low, a manual single-cylinder (station) supply is appropriate. The cylinder must be changed when the pressure becomes marginally low, which will require an interruption in the supply. The same system also could be used for greater demands where a bank of cylinders is installed. When an uninterrupted supply is required, some method of automatic changeover must be used.

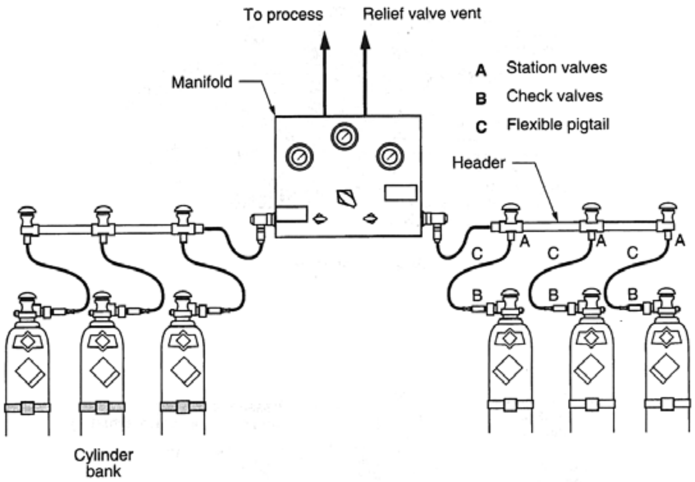

Figure 12-3 Typical Manifold Assembly
Source: Scott

Manifolds can be specified with manual or automatic changeover. The simplest and least costly of the automatic types is the semiautomatic or differential type of changeover manifold. For this type of installation, the regulators for each bank of cylinders are manually set at different pressures. Usually, the secondary bank is set 5 psig lower than the primary bank. When the pressure of the primary bank falls below the lower setting of the reserve bank, the secondary bank automatically becomes the primary supply by default, since it has a higher pressure than the primary bank. A low-pressure alarm or low-pressure gauge reading will indicate that the changeover has taken place. To change the cylinders, the empty bank first must be manually isolated. Then the pressures on the respective primary and secondary regulators must be reset to reflect the 5-psig difference between the former reserve supply, which is now the primary supply, and vice versa.

In other types of semiautomatic manifolds, the changeover is fully automatic, but a switch must be manually turned from the reserve position to the primary position when changing cylinders.

The fully automatic changeover manifold uses pressure switches or transducers to sense changes in line and supply pressures. This in turn sends an electric signal to a relay that turns off or on the appropriate valves that accomplish the changeover with no variation in system delivery pressure. It also changes the secondary operating bank indicator to primary. In addition, an alarm is sent when the cylinders need to be changed. For critical applications, connection of the power supply to optional standby power should be considered.

A typical manifold assembly is illustrated in Figure 12-3. Exact manifold dimensions vary and need to be obtained from the manufacturer.

Regulators

A regulator is a device used to reduce a variable high inlet pressure to a constant lower outlet pressure. The two broad categories of regulators are cylinder and line. Cylinder pressure regulators are mounted directly on high-pressure cylinders to reduce high-pressure gases, generally in the range of 2,000 to 6,000 psig (13,789.5 to 41,368.5 kPa), to a lower pressure, generally around 150 psig (1,034.2 kPa). Line regulators are inline devices used to reduce a higher pressure to a lower working pressure of 55 psig (379.2 kPa) and also are used on cryogenic tanks to reduce the pressure of the vapor above the vaporized liquid, generally in the range of 150 to 250 psig (1,034.2 to 1,723.7 kPa).

The regulator is the first device installed in the distribution system. Depending on the purity of the gas, an integral inlet filter should be considered to keep particulates from entering the regulator.

Regulators are available in two types: single and double stage (see Figure 12-4). The single stage is less costly and less accurate. This type should be chosen if maintenance of an exact pressure is not a major factor in system operation. The double stage is more costly and more accurate and able to achieve a constant outlet pressure within a narrow operating range. When selecting a regulator for specific accuracy requirements, obtain the accuracy envelope diagrams from the manufacturer to check the device's parameters using actual anticipated system design pressures and flow rates.

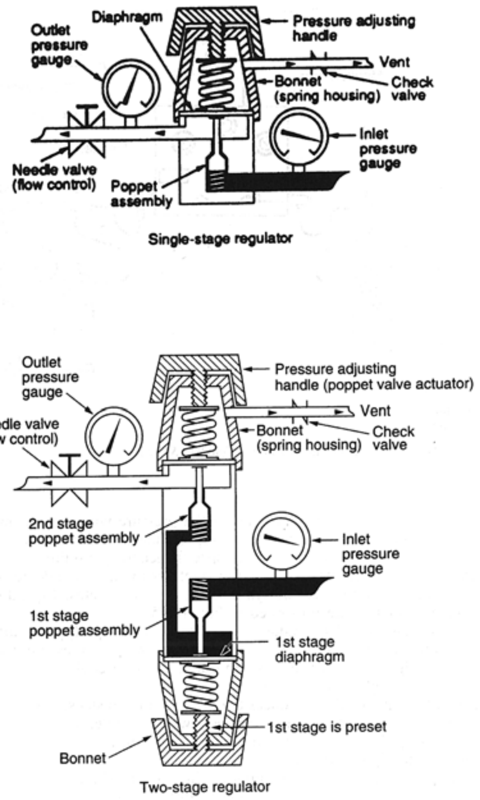

Figure 12-4 Typical Single- and Double-Stage Regulators
Source: Scott

The single-stage regulator reduces pressure in one step. Typical differences in outlet pressures could vary as much as 7 psig (48.2 kPa) from low to high flow rates. The double-stage regulator reduces the pressure in two steps. Typical differences in outlet pressure could vary as much as 3 psig (20.7 kPa) from low to high flow rates.

Another parameter that may be important in some installations is regulator creep, or a rise in delivery pressure due to differences in motion of internal mechanical components caused by aging. Creep is also caused by foreign material interfering with the mechanical operation of the unit. This is the most common cause of unit failure.

The following should be considered when selecting a regulator:

- The regulator should have a positive gas vent.
- The regulator must be rated for the highest possible working pressure.
- The delivery pressure range must be adequate.
- The operating temperature must be compatible with the environment in which the regulator is located.
- The body and internal materials should be selected for the specific purity of the desired gas, such as being machine welded or having diffusion-resistant materials and packing
- High-purity regulators shall have little dead space internally and diaphragm seals that are consistent with the required purity.
- The pressure range of the gauges must be compatible with the pressures expected. As an ideal, the working pressure should be one-half of the maximum outlet gauge reading.

One feature that should be considered when only gas is to be used from a bulk liquid supply is an internal tank piping arrangement called an economizer. Provided as an integral part of the tank, this allows use of the gas available in the vapor space above the liquid in the tank before the liquid itself has to be vaporized. A special type of pressure regulator shall be provided that will switch from the economizer to the liquid line when the pressure in the vapor space falls below a preset level.

Filters and Purifiers

Filters and purifiers are necessary to reduce or eliminate unwanted contaminants and particulates in the gas stream. The most common purifiers are those used to remove oxygen, water vapor, hydrocarbons, and particulates. To deliver sterile gases, a 0.2-µ filter is used to remove any organisms suspended in the air stream. Filters also are used to eliminate other unwanted trace elements.

Many different types of filters are available. To remove hydrogen, palladium filters are used. Ceramic, fiberglass, sintered metal, and other adsorbent materials are used to remove oil, moisture, and other trace contaminants to make the main gas as pure as possible. The molecular sieve filter is a synthetically produced crystalline metal powder that has been activated for adsorption by removing the water of hydration. This material is manufactured with precise and uniform sizes and dimensions. The size determines what can be filtered. Sieves are available as a powder, pellets, beads, and mesh, although mesh is not used in laboratories.

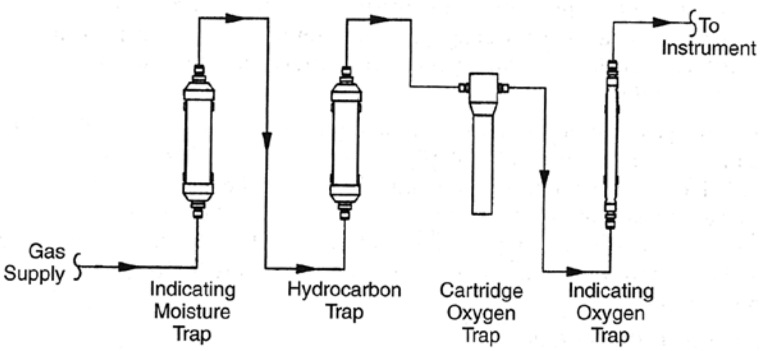

Figure 12-5 Typical Purifier Arrangement

The requirements of the end user will dictate the filter medium and type. A filter shall be placed before any flow meter and any other type of equipment where required. The housing must be compatible with the gas being filtered and the pressure involved. No filter should be subject to pressures more than the 60 psig (413.7 kPa) normally used in most laboratories unless specified for a higher pressure.

The pressure drop through the medium is a critical factor in the selection of the material used. For large installations, pressure gauges on each side of filters are used to monitor their effectiveness. Usually, a 5-psig (34.5-kPa) drop means that replacement is required. For some mediums, colored materials can be added to indicate when it is time for replacement.

It is not possible to improve the purity of a gas with the use of purifiers. If a gas of a certain purity is required, a gas of that grade must be used from the outset.

Refer to Figure 12-5 for a typical system purifier arrangement. Components shall be eliminated as required.

Gauges

Gauges (other than those integral to regulators) for pressures up to 10 psig (68.9 kPa) are usually the diaphragm sensing-element type. For pressures more than 10 psig (68.9 kPa), use the bourdon style. They should be cleaned for oxygen service, and the materials must be compatible with the gas being used. For single gauges, provide a small gas cock of the needle valve type between the pipeline and the gauge to shut off the flow and allow the gauge to be replaced without shutting down the system.

Flash Arresters

Flash arresters are required when the gas being used is flammable, particularly hydrogen and acetylene. They are mounted inline to prevent any flame from going back into the tank in the event that gas in the delivery piping system has ignited. It is standard procedure for a check valve to be made an integral part of a flash arrester, although this is not true in all cases.

Valves

Valves are an often-overlooked component of any system, but the selection of valve types and materials is important to efficiency and operating life. The valves used should have been designed for the type of service for which they will be used. Be careful to examine valve specifications for airway ports or openings smaller than the nominal size indicated or expected.

The most often-used shutoff valves are ball valves. Three-piece valves are the most desired because the body can be separated from the end connections when being installed and serviced. For exact control and modulating purposes, needle valves are used because of the precise level of control allowed. For specialty applications, diffusion-resistant valves reduce or eliminate unwanted gases from entering the system through the packing. Where purity is a major consideration, packless and bellows-sealed diaphragm valves are available.

The following should be considered when selecting valves:

- The most important valve feature is minimum flow restriction (pressure drop) when the valve is open full. Ball, gate, and plug valves have the lowest pressure drop, so it is extremely rare to use these types for flow restriction. Where this feature is important, the needle type of valve is used.
- The pressure rating should be suitable for the maximum pressure possible.
- The valve body and seat materials must be compatible with the expected trace gases and contaminants.
- Positive shutoff must be possible.
- Minimum or no leakage should occur through the valve stem.

Flow Limit Shutoff Valve

A flow limit shutoff valve automatically shuts off the flow from a cylinder if the flow rate exceeds a predetermined limit, usually about 10 times the highest expected flow rate. This valve must be manually reset after operation.

Check Valve

Check valves are used to prevent the reverse flow of gas in the delivery piping system. If one gas at a higher pressure possibly may force its way into another piping system or if system failure is a possibility, a check valve shall be installed.

Relief Valve

Relief valves are used to protect a system from overpressure. A relief valve must be provided between the regulator and the first shutoff valve in the system, with the discharge independently piped outdoors (see Figure 12-6). The discharge from a single gas service manifold or regulator may be connected, but no connection from any source to a relief discharge may be made from any other system. The discharge pipe should be a minimum of ¾ inch in diameter.

The relief valve shall be located at the first point in the system that could be subject to full cylinder pressure if the regulator failed. No valve should be located between the relief valve and the regulator. The relief valve release point should be set to 50 percent above the working pressure.

When two-stage regulators are used, a preset first-stage (or interstage) relief valve is sometimes required to protect the second stage from overpressure. Additionally, it is good practice to install an adjustable relief valve on the second stage to protect the system and instruments from damage due to excessive pressure. For outdoor installations involving inert gases, the relief valve can exhaust directly to the atmosphere. For indoor installations or any installation involving toxic or flammable gases, the relief valve exhaust should be captured and vented to a safe location outside.

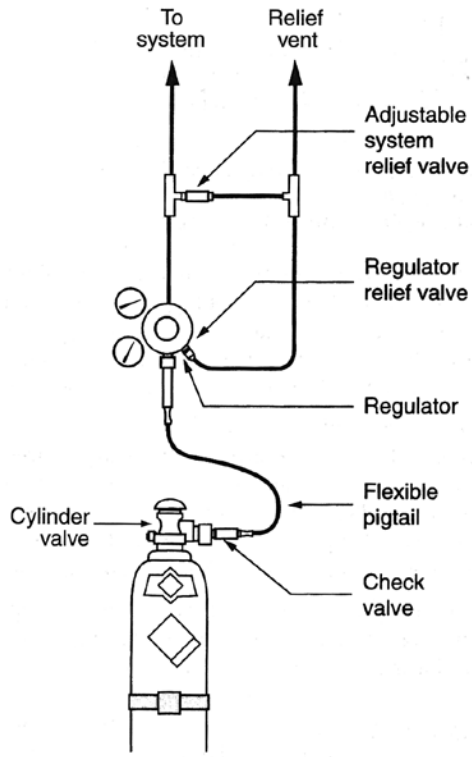

Figure 12-6 Relief Venting

Manifold and Regulator Purge Devices

The replacement of cylinders introduces unwanted room air into the piping manifold assembly and the connecting cylinder pigtails. When maintaining a high-purity level of the gas is necessary, purge valves are installed to run system gas through the contaminated parts of the system to replace all such air. The purge valve outlet should be vented outside the building. If the gas is suitable and low enough in volume and the storage room is large enough and well ventilated, it could discharge into the room since the purge volume used is generally quite small.

The regulator often requires special purging techniques recommended by the manufacturer. Purge gas shall be taken from a dedicated source used only for this purpose as shown in Figure 12-7.

Flow Measurement

Flow meters can be either of two types: electric or mechanical. The mechanical kind is called a variable-area type and uses a small ball as an indicator in a variable-area vertical tube. The type of mechanical meter most often used has an accuracy of 10 percent full scale. This means

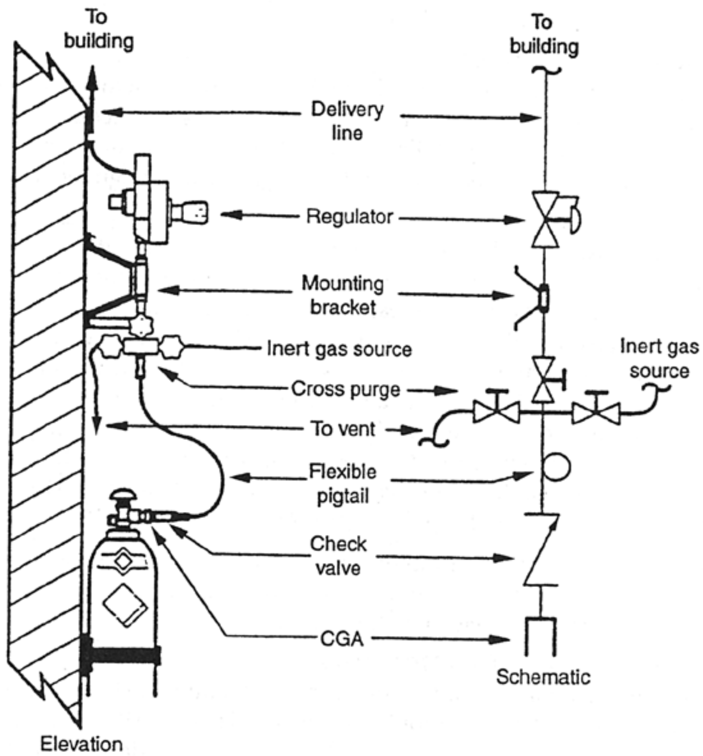

Figure 12-7 Regulator Purging Arrangement

that if the flow range is from 1 to 10 standard cubic feet per minute (scfm), the accuracy is ±1 actual cubic feet per minute (acfm). However, more accurate variable-area flow meters are available.

Mass flow meters are electronically operated, using the difference in temperature that gas creates when flowing over a heated element. The mass flow meter is very accurate, but expensive.

Gas Warmers

On occasion, the gas in cylinders is withdrawn so fast that the regulator could freeze because of the change in temperature. If this occurs, an electrically heated gas warmer is available to be installed inline, and this warmer heats the gas out of the cylinder before it reaches the regulator. The rule of thumb is to consider a warmer if the use of gas exceeds 35 acfm. The actual figure should be based on the specific type of gas being used, so consult with the supplier. Carbon dioxide, for example, presents a particular problem.

On occasion, the temperature of the delivered gas is a critical factor. If a low temperature could harm instruments or interfere with the procedures being conducted, a low-temperature cutoff should be installed with a solenoid valve to stop the flow of gas. If this happens often, a gas warmer might be required.

Alarms

Alarms are necessary to alert the user to immediate or potential trouble. They could be visible and/or audible. The typical alarms are high system pressure, low system pressure, and reserve in use. In some installations, a normal light is also requested. If a single cylinder is the sole source of supply, an alarm might be installed when the pressure in the tank reaches 400 psig (2,757.9 kPa). Other alarms could be provided that will indicate high pressure loss at filters, low gas temperature, purifiers at capacity limit, and flow limit valve operation.

These alarms are usually installed in an alarm panel, which can be mounted in the room where the gases are stored, in a constantly occupied location such as a receptionist area, or in the laboratory itself, depending on the availability and level of maintenance. Often, multiple locations are desirable if a continued supply of gas is critical. Various devices must be placed in the system for these alarms to function, such as pressure switches, transducers, and auxiliary contacts in a manifold assembly to transmit the alarm signal to the alarm panel.

Toxic and Flammable Gas Monitors

If a toxic and/or flammable gas might accumulate in an enclosed area or room, a gas monitor must be installed to signal an alarm if the gas percentage rises above a predetermined limit that is considered harmful or dangerous. This should be 50 percent of either the lower flammability limit or the level of concentration that may cause ill effects or breathing problems. (The oxygen concentration of the ambient air should never be allowed to fall below 19.5 percent.) Refer back to Table 12-1 for the flammability limits of some of the more common gases. Request the MSDS for gases not listed.

In addition, much lower levels should also be alarmed to indicate that a problem exists well before the evacuation of an area is required because of a leak.

Gas Mixers

For certain applications, gas mixers are available to accurately mix different gases to produce various proportions. The accuracy of the mixture, flow rates of the various gases, and the compatibility of the piping materials and the gases are considerations in the selection of the mixer.

Vibration Isolation

Vibration isolation is achieved by the proper selection of resilient devices between the pump base and the building structure. This isolation is accomplished by placing isolators between the pump and the floor, flexible connections on all piping from the compressor, and spring-type hangers on the piping around the compressor.

DISTRIBUTION NETWORK

System Pressure

Unless otherwise instructed, it is generally accepted practice to use a pressure of 50 to 55 psig (344.7 to 379.2 kPa) in the normal centralized piping distribution system, with a nominal 5-psig (34.5-kPa) loss in the system. High-pressure systems, if specifically requested by the end user or required by the laboratory equipment manufacturer, use a different pressure. Accepted practice limits the allowable friction loss in the piping system to 10 percent of the initial pressure. These figures are not set in stone and should be adjusted for specific conditions or special systems when necessary. The most important consideration is the actual pressure required by the equipment being used. The maximum pressure set by a regulator should be 10 psi (69 kPa) above the minimum pressure recommended by the manufacturer or end user.

Pipe Material Selection

Consider the following when selecting the pipe material and type for a specialty gas system:

- Compatibility with the specific gas used
- Capability of delivering the desired gas purity for the anticipated usage
- Pressure rating of the pipe and joining methods
- Temperature rating and the ability to be cleaned or sterilized in place
- Joining method

If all elements are equal, the least expensive piping shall be selected. Refer to the manufacturer or supplier of the gas for pipe compatibility.

The pipe most often used to maintain the highest purity is grade 304L or 316L stainless steel tubing conforming to ASTM A270: *Standard Specification for Seamless and Welded Austenitic and Ferritic/Austenitic Stainless Steel Sanitary Tubing*. The interior should be electropolished, and the exterior could be mill finished in concealed spaces. In exposed locations and where the pipe exterior will be sterilized or cleaned, the pipe exterior should have a No. 4 finish. Stainless steel pipe is capable of withstanding repeated sterilization by steam and a variety of chemicals. The pipe is joined by orbital welding, so the tube should have a minimum wall thickness of 0.65 inch to be welded. When welding is not required, a tube wall thickness of 0.28 inch is commonly used, but the wall thickness must be able to handle the working pressure of the system.

When hard pipe is not desired or used from a cylinder or system to a movable instrument, it is common practice to use 1/8-inch (6-mm) polyethylene (PE), stainless steel, or copper tubing of a sufficient pressure rating and compatibility with the specific gas, with no joints between the cylinder and instrument.

In many laboratory applications, maintaining ultra-high purity of a gas from the storage tank to the outlet is not an absolute requirement. For this type of service, copper tube and fittings that have been cleaned for oxygen service and joined by brazing and properly purged often are used, including the following grades:

- ASTM B88: *Standard Specification for Seamless Copper Water Tube*
- ASTM B819: *Standard Specification for Seamless Copper Tube for Medical Gas Systems*
- ASTM B280: *Standard Specification for Seamless Copper Tube for Air-Conditioning and Refrigeration Field Service*
- ASTM B75: *Standard Specification for Seamless Copper Tube*

Another type of material for noncritical applications is aluminum tubing (ASTM B210: *Standard Specification for Aluminum and Aluminum-Alloy Drawn Seamless Tubes*) alloy 6061, T4 or T6 temper. This pipe is commonly joined by patented flare joints.

The pipe pressure rating is selected to resist the highest system design pressure, which is usually in the range of 50 to 55 psig (344.7 to 379.2 kPa). Copper tubing type L is used for pressures up to 200 psig (1,379 kPa), and type K is used for pressures up to 300 psig (2,068.4 kPa). The pressures are lowered internally at the equipment if the supplied pressure is too great. Based on experience, the allowable pressure range is usually between 30 and 75 psig (206.8 and 517.1 kPa). Higher pressures in the 300 psig (2,068.4 kPa) range for special uses are well within the limits of piping with flared, orbital welded, and brazed joints. The allowable pressure ratings for the various piping materials at ambient temperatures based on wall thickness values are calculated from equations appearing in ASME B31.3: *Process Piping*.

The piping system also shall be capable of being cleaned and sterilized in place, often, if required. Cleaned in place (CIP) uses chemicals, so the pipe must be able to resist corrosion. Refer to the manufacturer's literature to establish compatibility. Steam in place (SIP) raises the distribution system to a high temperature that kills microbes. A drain for the system is often required. The piping system materials need to be steam compatible for the temperatures that may be experienced.

Another consideration in maintaining a high-purity gas is outgassing. This is a phenomenon in which a gas under pressure is absorbed into any porous material. This occurs primarily in elastomers used as gaskets or seals and to some lesser extent in metallic and plastic pipe and tubing materials. When the pressure is reduced or eliminated, such as when changing cylinder banks or during maintenance, the absorbed gases are spontaneously given off, adding impurities to the gas piping system.

Experience has shown that reaming the ends of pipe or tubing to obtain a smooth interior can leave pieces of shaved metal in the pipe. If this is a cause for concern, reaming methods and tools are available that eliminate this problem.

Joints

The joining method may be a criterion in the selection of the pipe wall thickness or pipe material composition. The temper of the pipe may have to be carefully selected to use proprietary fittings.

The most often-used joints for copper tubing are brazed. No flux is permitted, so only cast or wrought copper fittings should be used. The interior of the joint shall be purged with an inert gas, such as nitrogen type NF or argon. The reason for making up a joint in this manner is to eliminate any residue that may be produced as a by-product of the brazing process.

For stainless steel pipe, orbital welding leaves the smoothest interior surface, but it should be used only on tubing with a wall thickness of 0.65 inch or thicker. Another type of joint that can be used is the patented flared joint, which is preferable to solder or brazed joints that often leave a residue that contributes particulates to the gas stream. In addition, the flared joint is popular because it can be made up using only a saw and some wrenches. When copper tubing is used with flared joints, the pipe shall not have embossed identification stamped into the pipe because doing so causes leaks at the joint. There is no ASTM designation for patented flared joints, but they are acceptable for all applications as long as the allowable joint pressure ratings are not exceeded.

PIPE SIZING AND LAYOUT

Before laying out the piping system, the following information must be known:

- All air- or gas-consuming devices
- Minimum and maximum pressure requirements for each device
- Actual volume of air or gas used by each device
- Suggested duty cycle and diversity factor for equipment
- Special individual air or gas purification requirements

System Sizing Procedure

Following is a recommended system sizing procedure. It is not intended for compressed air in common laboratories. Refer to Chapter 9 for that information.

1. Locate the gas storage area and lay out the cylinders, manifolds, and so on.

2. Establish a general layout of the system from the storage area to the farthest outlet or use point. Measure the actual distance along the run of pipe to the most remote outlet. Next, add a fitting allowance. For ease of calculations, the addition of 50 percent of the actual measured run will give a conservative approximation of the entire system. Adding the measured length to the fitting allowance will result in the equivalent run of pipe.
3. Choose all of the filters, purifiers, and accessories necessary for system purity. This will establish a combined allowable pressure drop through each of them and the assembly as a whole.
4. Establish the actual pressure required at the farthest outlet.
5. Calculate the allowable total system friction loss.
   - It is accepted practice for general use to have a minimum system pressure of 45 to 55 psig (310.3 to 379.2 kPa) and to allow 5 psig (34.5 kPa) as a pressure loss in the pipe. For high-pressure systems serving specific equipment or tools, start with the high end of the range for the actual pressure required. Accepted practice is to allow 10 percent of the proposed system pressure for pipe friction loss, so for a 125-psig (861.8-kPa) system, a ±12-psig (82.7-kPa) friction loss will be allowed. This figure is variable. To that figure add the pressure required to overcome the drop through the filter-purifier-manifold assembly and other accessories.
   - Divide the total equivalent run of pipe (in hundreds of feet) by the allowable friction loss to calculate the allowable friction loss in psig per 100 feet of pipe. This calculation is necessary to allow the use of the sizing chart provided in this chapter. If other methods are used to indicate friction loss in the piping system, calculate the loss in that specific method.
6. Calculate the connected flow rate for the piping to be sized. For general use, a flow rate of 1 scfm (30 nLpm) for each outlet can be used unless the end user indicates otherwise. Calculate the scfm (nLpm) of gas through each branch, from the farthest outlet back to the source (or main). For specific equipment, use the flow rate recommended by the manufacturer.
7. Calculate the expected flow rate for all points using the appropriate diversity factor for all parts of the system. For specific equipment, the diversity factor must be obtained from the end user. The diversity (or simultaneous use) factor, which determines the maximum number of outlets in use at any one time, has a major influence on the sizing of the piping system. Specialty gas systems have no exact calculation method, so consultation with the end user is the best method and is strongly suggested.
8. The sizing chart, Table 12-2, has been calculated for a gas with a specific gravity of 1 (which is air), using type L copper pipe and a pressure of 55 psig (379.2 kPa). This table also can be used for gases with a specific gravity ranging from 1.90 to 1.10. Slight differences are well within accepted accuracy. To find the specific gravity of many common gases, refer back to Table 12-1.
   - With all the above information available, the pipe can now be sized. Starting from the most remote point on the branch and then proceeding to the main, calculate the actual flow rate using the appropriate diversity factor. Enter Table 12-2 with the actual flow rate and the allowable friction loss. Find the flow rate, and then read across to find a friction loss figure that is equal to or less than the allowable friction loss. Read up the column to find the pipe size. In some cases, the diversity factor for the next highest range of outlets may result in a smaller-size pipe than the range calculated. If this occurs, do not reduce the size of the pipe; keep the larger size previously determined. For equipment using capillary piping and tubing, refer to Figure 12-8 for nominal 1/8-inch pipe.

Table 12-2 Pipe Sizing for Oxygen, Nitrogen, and Air, Copper Tube Type L, 55 psi, Specific Gravity = 1, psi per 100 feet of pipe

scfm	acfm	½ in.	¾ in.	1 in.	1¼ in.	1½ in.	2 in.	2½ in.	3 in.	4 in.
5	1.1	0.15	0.04	0.01						
10	2.2	0.51	0.13	0.04	0.01					
15	3.3	1.04	0.27	0.09	0.02	0.01				
20	4.3		0.45	0.14	0.04	0.02				
25	5.4		0.67	0.21	0.06	0.03	0.01			
30	6.5		0.93	0.29	0.08	0.04	0.01			
35	7.6		1.18	0.39	0.10	0.05	0.02	0.01		
40	8.7			0.49	0.13	0.06	0.02	0.01		
45	9.8			0.60	0.16	0.08	0.02	0.01		
50	10.9			0.73	0.20	0.09	0.03	0.01		
60	13.0			1.01	0.27	0.13	0.04	0.02	0.01	
70	15.2			1.28	0.36	0.17	0.05	0.02	0.01	
80	17.4				0.45	0.22	0.07	0.03	0.01	
90	19.5				0.56	0.27	0.08	0.03	0.01	
100	21.7				0.68	0.32	0.10	0.04	0.02	0.00
110	23.9				0.81	0.38	0.12	0.05	0.02	0.01
120	26.0				0.94	0.45	0.14	0.06	0.02	0.01

Table 12-2 Pipe Sizing for Oxygen, Nitrogen, and Air, Copper Tube Type L, 55 psi, Specific Gravity = 1, psi per 100 feet of pipe (continued)										
scfm	**acfm**	**½ in.**	**¾ in.**	**1 in.**	**1¼ in.**	**1½ in.**	**2 in.**	**2½ in.**	**3 in.**	**4 in.**
130	28.2				1.09	0.52	0.16	0.07	0.02	0.01
140	30.4				1.22	0.59	0.18	0.08	0.03	0.01
150	32.6					0.67	0.20	0.09	0.03	0.01
175	38.0					0.89	0.27	0.11	0.04	0.01
200	43.4					1.13	0.34	0.14	0.05	0.01
225	48.8					1.28	0.42	0.18	0.06	0.02
250	54.3						0.51	0.22	0.08	0.02
275	59.7						0.60	0.26	0.09	0.02
300	65.1						0.71	0.30	0.11	0.03
325	70.5						0.82	0.35	0.12	0.03
350	76.0						0.94	0.40	0.14	0.04
375	81.4						1.06	0.45	0.16	0.04
400	86.8						1.18	0.51	0.18	0.05
450	97.7							0.63	0.22	0.06
500	108.5							0.76	0.27	0.07
550	119.4							0.90	0.32	0.09
600	130.2							1.06	0.37	0.10
650	141.1							1.21	0.43	0.12
700	151.9								0.49	0.13
750	162.8								0.56	0.15
800	173.6								0.63	0.17
850	184.5								0.70	0.19
900	195.3								0.78	0.21
950	206.2								0.89	0.23
1,000	217.0									0.25
1,100	238.7									0.30
1,200	260.4									0.35
1,300	282.1									0.41
1,400	303.8									0.47
1,500	325.5									0.53
Note: Values in table are for flow velocities not exceeding 4,000 fpm.										

- To calculate the specific gravity of any gas not covered in Table 12-1, divide the molecular weight of that gas by 29, which is the composite molecular weight of air.
- When any gas with a specific gravity other than 1 is used, an adjustment factor is provided in Table 12-3 that will convert scfm to the equivalent of any other gas or combination of gases for use in Table 12-2. Multiply the factor found in the table by the flow rate to obtain the new flow rate for the gas in question.
- For pressures other than 55 psig (379.2 kPa), use the following formula:

Equation 12-2

$$PD = \frac{P_1 + 14.7}{P_2 + 14.7} \times PD_r$$

- For the flow of any compressed gas at a temperature other than 60°F (15.6°C), use the following formula to calculate a factor that, when multiplied by the flow rate, will give the flow rate at the new temperature:

Equation 12-3

$$f = \frac{460 + t}{520}$$

where:

PD = New pressure drop, psig (kPa)

P_1 = 55 (referenced table pressure), psig (kPa)

P_2 = Actual service pressure, psig (kPa)

PD_r = Referenced pressure drop found in Table 12-2, psi/100 feet (kPa/30m)

t = Temperature under consideration, °F (°C)

f = Factor

- Having calculated the scfm and the allowable friction loss in each section of the piping being sized, now size the piping using the charts for system pressure. Since all pipe sizing charts are formulated on the loss of pressure per some length of piping (usually 100 feet), it will be necessary to arrive at the required value for the chart being used. A maximum velocity of 4,000 fpm (1,200 m/min) is recommended.

Another sizing method, applicable only to branch lines with small numbers of laboratory outlets used for average purposes, is to use a prepared chart based on the number of outlets with the actual flow of the gas not considered. The flow rate and diversity of use are taken into consideration in the sizing chart, which assumes that sufficient system pressure is available. With a small number of outlets on a branch, this method provides a sufficient degree of accuracy and speed of calculation. Table 12-4 is such a chart for various systems found in a typical laboratory.

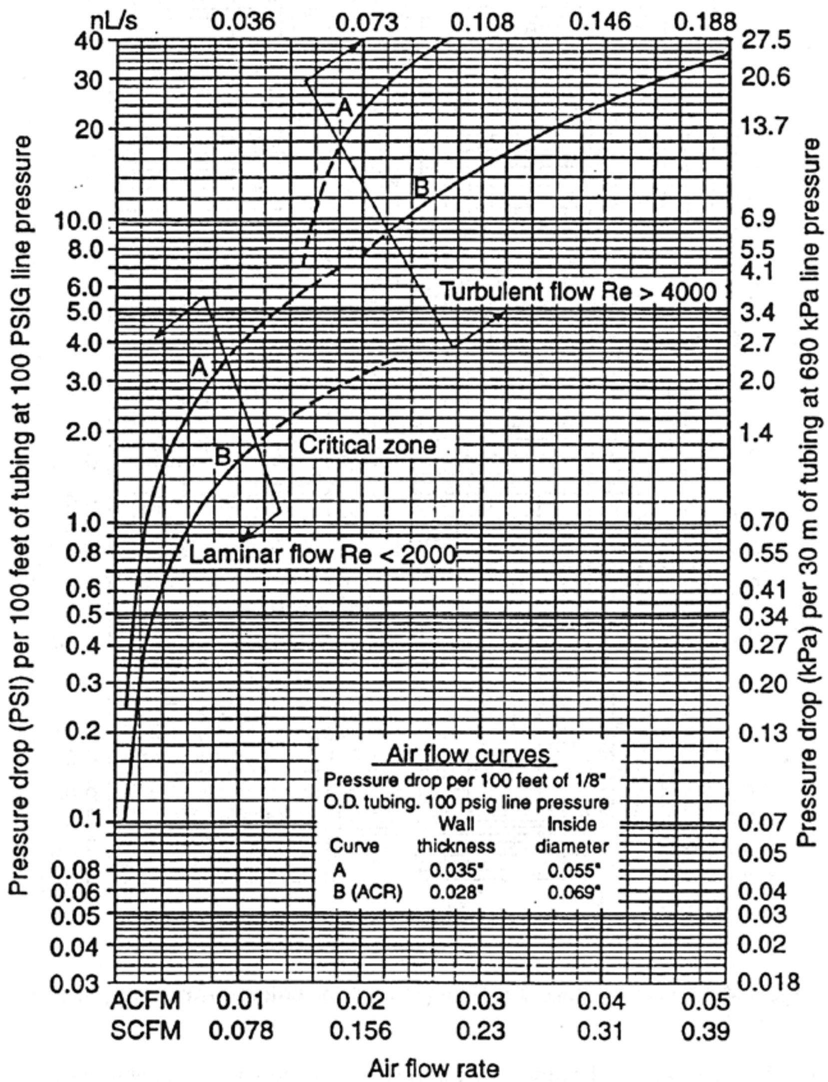

Figure 12-8 Sizing 1/8-inch OD Capillary Piping and Tubing

Table 12-3 Factors for the Sizing of Any Gas Based on Specific Gravity

Specific Gravity	Factor
.05	4.50
.10	3.16
.15	2.58
.20	2.20
.25	2.00
.30	1.79
.35	1.68
.40	1.57
.45	1.49
.50	1.41
.55	1.33
.60	1.28
.65	1.23
.70	1.19
.75	1.15
.80	1.12
.85	1.07
.90	1.05
.95	1.02
1.00	1.00
1.10	.95
1.20	.91
1.30	.87
1.40	.85
1.50	.81
1.60	.78
1.70	.76
1.80	.74
1.90	.72
2.00	.70
2.10	.69
2.20	.67
2.30	.65
2.40	.63
2.50	.62
2.60	.61
2.70	.60
3.00	.56
4.50	.25

Note: Multiply factor by scfm in Table 12-8. Calculate adjusted scfm. Use adjusted scfm to obtain friction loss.

COMPRESSOR INLET PIPING

Since air compressor performance depends on inlet conditions, this system deserves special care. The air intake should provide a supply of air to the compressor that is as clean, cool, and dry as possible. The proposed location should be studied for the presence of any type of airborne contamination and positioned to avoid the probability of a contaminated intake. Intake piping is discussed in Chapter 9. For sizing intake piping, refer to Table 12-5.

Table 12-4 Typical Laboratory Branch Sizing Chart

Number of Connections	Pipe Diameter, in.						
	Cold and Hot Water	Air	Gas	Vacuum	Oxygen	D.W.	Nitrogen
1	½	½	½	½	½	½	½
2	¾	½	½	½	½	½	½
3	¾	½	½	¾	½	½	½
4	¾	½	½	¾	½	½	½
5	¾	½	¾	¾	½	¾	½
6	¾	½	¾	1	½	¾	½
7	1	½	¾	1	½	¾	½
8	1	½	¾	1	½	1	½
9	1	½	¾	1	½	1	½
10	1	½	¾	1	½	1	½
11–20	1¼	¾	1	1¼	¾	1	¾
21 and over	1½	1	1¼	1½	1 (21–30) 1¼ (31–50) 1½ (51+)	1	1

Note: 1 in. = 25.4 mm

PRESSURE TESTS

Bulk storage tanks and dewars are required to be ASME rated and therefore are tested at the factory before shipment. They are not tested after installation. Cylinders are not tested for the same reason. This means that only the distribution system, from the cylinder valve to the outlets, must be subject to pressure tests.

Testing is done by pressurizing the system to the test pressure with an inert, oil-free, and dry gas. Nitrogen is often used because of its low cost and availability. The system test pressure for low-pressure systems is 150 percent over the working pressure. For systems with a working pressure up to 200 psig (1,379 kPa), the entire piping system, including the cylinder manifold, is tested to 300 psig (2,068.4 kPa) for one hour with no leakage permitted. If a working pressure higher than 200 psig (1,379 kPa) is required, the system is tested at 150 percent of the system pressure.

The pressure testing should be done in increments of 100 psig (689.5 kPa), starting with 100 psig. This is done to avoid damage due to a catastrophic failure. Leaks are repaired after each increment. After final testing, it is recommended that the piping be left pressurized at the system working pressure with the system gas if practical.

Table 12-5 Recommended Air Compressor Inlet Pipe Size

Maximum scfm Free Air Capacity	Minimum Size, in.
50	2½
110	3
210	4
400	5
800	6

Note: 1 cfm = 0.03 m³/min
Source: James Church

FLUSHING, TESTING, AND PURGING THE DISTRIBUTION SYSTEM

After the system is completely installed and before it is placed in service, the piping system first must be flushed to remove all loose debris, then tested, and finally purged with the intended system gas to ensure purity.

An accepted flushing method is to allow a volume of two to five times the expected flow through each respective part of the system. This is done by connecting the flushing gas under pressure to the piping system and then opening and closing all outlets and valves starting from the closest and working to the most remote.

To test for particulates, flow the gas into a clean white cloth at a minimum rate of 15 cfm (100 L/min) and inspect the cloth for contamination.

Finally, the system must be capable of providing the desired purity when actually placed in operation. Since flushing and testing may leave the piping system filled with inert or other gases, they must be removed, or purged. This is accomplished by allowing the system gas to flow through all parts of the piping system, opening all of the valves, and testing the gas purity at various points of the system until the desired purity level is reached. For high-purity gases, a laboratory specializing in testing for the purity level required shall be used unless the facility is capable of performing the test.

It is often best to use the system gas for testing purposes.

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Expiration date: Continuing education credit will be given for this examination through **July 31, 2019**.

CE Questions — "Laboratory Gases" (CEU 261)
Test written by David Bailey, CPD, GPD, EIT, FASPE

1. Material safety data sheets pertaining to the EPA's ratings and associated precautions for specialty gases address which of the following hazard classifications?
   a. fire
   b. health
   c. sudden release of pressure
   d. all of the above

2. Gases that react with heat and water may form acids that are potentially harmful to a piping system. That would include which of the following?
   a. carbon dioxide
   b. nitrogen compounds
   c. sulfur dioxide
   d. all of the above

3. Even though helium is an inert gas, high concentrations released in a confined space may result in ________.
   a. asphyxiation
   b. blindness
   c. irritation of human tissue
   d. lower explosive level (LEL)

4. When sizing a butane laboratory gas system based on its specific gravity, the adjustment factor that should be used is ________.
   a. 0.78
   b. 1.05
   c. 1.28
   d. 2.00

5. An economizer used in conjunction with the laboratory gas storage source ensures ________.
   a. that the delivery pressure range is adequate
   b. that the initial system delivery supply is vapor
   c. that the working pressure is one-half of the maximum acceptable design pressure
   d. that the delivery supply meets the desired specific purity

6. Laboratory gases may be stored in cylinders that are available in four general tank categories, one of which is not ________.
   a. aluminum
   b. carbon steel
   c. copper alloy
   d. stainless steel

7. For laboratory gas systems, the ________ valve is used for exact control and modulating purposes.
   a. gate
   b. needle
   c. plug
   d. three-piece ball

8. Copper tubing, type L, is often considered for use in laboratory gas systems (where the typical design pressures range from 50 psig to 55 psig) since its acceptable upper limit is ________ psig.
   a. 100
   b. 200
   c. 300
   d. 400

9. Regarding high-purity laboratory gas systems, outgassing may be a concern as a loss in system pressure could add impurities to the system due to ________.
   a. any porous system material
   b. faulty check valve
   c. regulator relief valve
   d. three-piece ball valve

10. The recommended minimum inlet pipe size for a compressor with an available free air capacity of 125 scfm is ________.
    a. 3 inches
    b. 4 inches
    c. 5 inches
    d. 6 inches

11. What inert gas is commonly used for pressure testing laboratory gas systems?
    a. argon
    b. helium
    c. nitrogen
    d. radon

12. When executing a pressure test on a 250-psig laboratory gas system, the minimum total number of incremental tests (inclusive of the final test) that should be performed is ________.
    a. one
    b. two
    c. three
    d. four